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EFFECT OF VARIOUS
ANNEALING CYCLES
ON INCONEL 718
MICROSTRUCTURE

REPORT A470 SERIAL NO. 20

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INDEX
CODE (Ni-4)(I-e)(IV-e)

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(Ni-4)(I-e)(IV-e)

LABORATORY: Structures

EFFECT OF VARIOUS ANNEALING CYCLES ON INCONEL 718 MICROSTRUCTURE

ABSTRACT

Metallographic studies were performed to investigate the effect of various annealing cycles on grain size and precipitate morphology in Inconel 718 nickel chromium alloy.

Test specimens of .040-inch material were overaged at 1400F for 30 hours and then annealed 15 minutes at 1500, 1600, 1700, 1750, 1800, 1900, 2000, 2100, and 2150F.

Before and after aging, the DPH hardness of all material was determined and photomicrographs at 250X and 2000X were prepared.

Annealing temperatures of 1500 and 1600F failed to produce satisfactory results. Annealing between 1700 and 1800F adequately dissolves precipitated phases so that subsequent aging produces maximum hardness.

Annealing overaged material at 1900F for 15 minutes appears to completely dissolve precipitate phases without altering precipitation behavior during subsequent aging or encouraging excessive grain growth.

When annealed at temperatures greater than 1900F, excessive grain growth can be expected. Precipitation behavior during subsequent aging also appears different with grain boundary films forming.

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Laboratory Project Engineer

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1. INTRODUCTION

Inconel 718 is a precipitation hardening, nickel base alloy which offers excellent strength up to 1200F and good weldability (reference 1). Nominal composition of the alloy is 52 Ni, 19 Cr, 3 Mo, 5 Cb + Ta, 0.8 Ti, 0.6 Al, 0.05C, and the remainder iron. Inconel 718 differs from other super alloys of its class in that aluminum and titanium are not the principal hardening elements. Instead, it is strengthened by a gamma prime type of precipitate containing a considerable amount of columbium as well as molybdenum, titanium, and possibly aluminum.

The precipitation hardening reaction of the alloy is relatively sluggish, a feature of the alloy attributed to relatively slow diffusion rates of the elements which produce strengthening. This slow aging response is of benefit to both fabrication and welding processes. Distortion is minimized while formability and weldability can be maintained at high levels because low annealed hardness is obtained by air cooling from annealing temperatures.

Inconel 718 is being used and planned for many applications at McDonnell. Because the principal hardening phase differs from other superalloys, precipitation behavior during heat treating should be expected to differ. At the present time information on the effect of commercial heat treatments on the precipitate morphology is not available in the literature. To investigate this factor, metallographic studies were performed to observe precipitation behavior after annealing at various temperatures.

The approximate formula of the principal strengthening phase in Inconel 718 is Ni_3(Cb, Mo, Ti). Previous work (references 2 and 3) indicates the phase to be metastable in nature and possesses a face centered cubic structure which is coherent with the austenitic matrix. X-ray diffraction work has shown the lattice parameter of Ni_3(Cb, Mo, Ti) precipitate is approximately 0.8% greater than the matrix which produces the strengthening lattice strain. The compound has been found to precipitate heavily during aging between 1300 and 1400F.

Aging for long times or at higher temperatures results in formation of stable Ni_3Cb compound with a hexagonal close-packed structure that is noncoherent with the matrix. Formation of Ni_3Cb relieves lattice strain and results in overaging. The compound is commonly observed as a coarse, acicular precipitate formed after aging long times at temperatures from 1300 to 1700F. It probably dissolves at temperatures in excess of 1850F.

As in most super alloys, the carbon present is tied up by columbium and some titanium as (Cb, Ti) C. The primary carbide phase occurs as coarse blocky particles randomly dispersed and relatively insensitive to temperature. Some solutioning of (Cb, Ti)C may occur around 2200F and permit reprecipitation during aging as a grain boundary film. In addition to the primary carbide, TiN

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1. INTRODUCTION (CONT'D.)

is also frequently observed as distinctly angular, randomly dispersed particles that are not dissolved at temperatures as high as 2250F.

While not normally observed in wrought Inconel 718, cast material has been found to possess additional phases. A Laves phase, M_2 (Cb, Ti), is commonly observed where M can be nickel, iron, or chromium and molybdenum may replace columbium and titanium in the radical (Cb, Ti). When wrought materials are solution treated at temperatures in excess 2250F M_2 (Cb, Ti) can be formed by incipient melting at the grain boundaries. In castings, acicular Ni_3Cb is observed to occur abundantly around M_2 (Cb, Ti) and form with greater rapidity than in wrought material. On this basis, it has been suggested that the presence of M_2 (Cb, Ti) may hasten the formation of acicular Ni_3Cb. Another carbide, Cr_7C_3, has also been found in cast materials associated with M_2 (Cb, Ti) and acicular Ni_3Cb. It is probable that Cr_7C_3 is formed only after appreciable amounts of columbium are tied up as M_2 (Cb, Ti) and/or Ni_3Cb. While these phases are not normally found in wrought Inconel 718, consideration will have to be given them in evaluating the welding behavior of the alloy.

This test was conducted by the Structures Laboratory, McDonnell Aircraft Corporation, during the period 2 July 1962 through 28 September 1962.

2. TEST MATERIALS

The material evaluated was Inconel 718 in the form of 0.040-inch sheet. Material was received in the mill-annealed temper with a pickled finish.

3. TEST SETUP AND PROCEDURE

Test specimens 0.040 x .05 x 1.0-inch were sheared from the as-received material. Except for retaining a sample of as-received material, all specimens were "overaged" at 1400F for 30 hours.

To determine the extent to which various annealing temperatures would eliminate the overaged structure, duplicate specimens were annealed 15 minutes at 1500, 1600, 1700, 1750, 1800, 1900, 2000, 2100 and 2150F. After annealing the duplicate specimens, one specimen was allowed to cool in still air, while the other was quenched in water.

All specimens were then sectioned and one-half mounted, DPH hardness was determined, and the specimens prepared for metallographic examination. Photomicrographs were then prepared of as-received material, overaged material, and the overaged material which was annealed at the 9 annealing temperatures.

The same procedure was repeated after aging per PS 15603.

3. TEST SETUP AND PROCEDURE (CONT'D.)

Overaging of the material which was subsequently annealed, and aging of the annealed material were performed in a Westinghouse circulating air heat-treating furnace. All annealing was performed in tubular furnaces normally used for mechanical property determinations. The specimens to be annealed were dropped into furnaces,at the desired temperature, along with a dummy specimen containing chromel-alumel thermocouples. Annealing time was assumed to start when temperature of the dummy specimen reached furnace temperature.

DPH hardness was determined using a Vickers Microhardness Tester and a 10 KG load.

All specimens were prepared for metallographic examination using normal mechanical polishing techniques. The specimens were etched electrolytically using an electrolyte of 50cc HCl, 50cc H_2O, and 14cc 3% H_2O_2 with a platinum cathode and open circuit potential of 2 volts.

4. RESULTS

Table 1 on page 10 gives the DPH hardness of the material after the various heating cycles. The same results are shown graphically in Figures 1A and 1B on pages 11 and 12. As-received hardness of the material was DPH 188 or R_B 91. Overaging 30-hours at 1400F resulted in a hardness increase to DPH 358 or R_c 39. Annealing at 1700 to 1800F restored the material to its original hardness of DPH 184 to 188 or R_B 90 to 91. Annealing at 1900F produced slightly lower annealed hardness (DPH 179 to 180 or R_B 89) while annealing at 2000 to 2150F produced significantly lower annealed hardness (DPH 151 to 157 or R_B 76 to 77). Water quenching or air cooling the .040-inch material from annealing temperatures, failed to produce any significant variation in hardness.

Aging the annealed material produced similar results. As-received material aged to a hardness of DPH 438 or R_c 46. The overaged material also increased in hardness after aging to DPH 401 or R_c 43. Material aged after annealing at 1700 to 1900F possessed hardness of DPH 432 to 442 or R_c 46, which is equivalent to the as-received material. Material annealed at 2000 to 2150F had a slightly lower hardness after aging, ranging from DPH 427 to 433 or R_c 43. However, considerable scatter exists in these results due to the coarse grain size which prevailed. Annealing at 1500 or 1600F appears unsatisfactory. Hardness remains at intermediate values between that of overaged and as-received material in both the annealed and aged conditions.

Figure 2 on page 13 shows the microstructure of as-received material 250X and 2000X.

Figure 3 on page 14 shows equivalent microstructures of material overaged for 30-hours at 1400F.

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4. RESULTS (CONT'D)

Microstructure of the material after the various annealing and subsequent aging cycles are shown in:

Figure	Page	Annealing Temperature
4 and 5	15 - 16	1500
6 and 7	17 - 18	1600
8 and 9	19 - 20	1700
10 and 11	21 - 22	1750
12 and 13	23 - 24	1800
14 and 15	25 - 26	1900
16 and 17	27 - 28	2000
18 and 19	29 - 30	2100
20 and 21	31 - 32	2150

Figures 22 and 23 on pages 33 and 34 show the microstructure at 250X of specimens aged after being annealed at 1800, 1900, 2000, 2100, and 2150F. Comparison of these photomicrographs shows the grain growth occurring after annealing at temperatures in excess of 1900F.

Average grain diameter of the material annealed at 1900F or below was 0.025 to 0.035 mm. Annealing at higher temperatures resulted in average grain diameters of 0.120 mm after 2000F, 0.150 after 2100F, and 0.150 to 0.200 after 2150F.

5. DISCUSSION OF RESULTS

In the mill-annealed condition, the microstructure of Inconel 718 consists of equiaxed grains showing extensive twinning which is characteristic of the austenitic matrix. The primary carbides, (Cb, Ti)C, can be observed as randomly dispersed particles. Also observable are networks of apparently spherical particles which seem to transcend the present equiaxed structure but delineate grain boundaries in a previous deformed structure.

Overaging 30 hours at 1400F results in precipitation that produces appreciable shading within the grains and visible precipitation at the grain boundaries. These effects are probably visible evidence of Ni_3Cb formation.

Annealing the overaged material 15 minutes at 1500F removes some of the shading from inside the grains, although it subsequently returns after aging, and induces coarser agglomeration of Ni_3Cb at the grain boundaries.

Annealing 15 minutes at 1600F removes most of the shading from the grains, although it again returns after aging, and produces extremely coarse, acicular agglomeration of Ni_3Cb at the grain boundaries.

5. DISCUSSION OF RESULTS (CONT'D.)

Material annealed from 1700 to 1800F and the as-received material show essentially the same structure when observed on the optical metallograph. All shading within the grains appears eliminated, even after subsequent aging, and the networks of small particles again can be observed to wander through the present structure. Appreciable amounts of coarse Ni_3Cb precipitate can still be observed at the grain boundaries. The size and amount of the Ni_3Cb, precipitate appears to decrease slightly as annealing temperature increases from 1700 to 1800F.

Annealing at 1900F for 15 minutes appears to eliminate any coarse grain boundary precipitation of Ni_3Cb. The networks of small particles through the structure still remain along with (Cb, Ti) C and some TiN.

Annealing at 2000 and 2100F for 15 minutes results in appreciable grain growth in the material. Except for the (Cb, Ti) C and TiN, all phases observable optically appear to have been completely taken in solution. However, subsequent aging produces visible precipitation at grain boundaries. This could be reprecipitation of the phase observed as the wandering networks in material annealed at 1900F and below. Annealing at 2150F produces noticeably heavier visible precipitation at grain boundaries after aging. In addition to the effects noted in material annealed at 2000 and 2100F, the 2150F anneal might partially dissolve the (Cb, Ti) C and redeposit it as films along grain boundaries and at twin bands.

6. CONCLUSIONS

Annealing aged Inconel 718 from 1700 to 1800F for 15 minutes will dissolve sufficient Ni_3Cb precipitate to allow subsequent aging to maximum hardness. While some coarse precipitate may still remain in the microstructure it does not appear to occur in sufficient quantities to affect mechanical properties and may serve a useful purpose by inhibiting grain growth.

Annealing aged Inconel 718 for 15 minutes at 1900F appears to completely take into solution all coarse Ni_3Cb present without affecting precipitation behavior during subsequent aging, or encouraging grain growth.

Excessive grain growth may be expected if annealing temperatures exceed 1900F, and subsequent precipitation behavior during aging may be altered enough to deleteriously affect mechanical properties.

No variation in hardness or microstructure was found to result from air cooling or water quenching from annealing temperatures.

7. RECOMMENDATIONS

An attempt should be made to identify the random networks observed in the microstructures, as well as the grain boundary precipitation resulting

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7. RECOMMENDATIONS (CONT'D)

from annealing temperatures in excess of 2000F. It would also be desirable to determine the effect of high temperature annealing cycles on ductility of the alloy. More knowledge in these areas will aid in understanding the welding behavior of the alloy.

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LIST OF EQUIPMENT AND INSTRUMENTS

Equipment and instruments used in this test are listed below. Applicable calibration records are available for inspection.

Item	Manufacturer and Model No.	Laboratory Number
Arcweld Creep Testing Furnace	Arcweld Manufacturing Company	USN 000091
Marshall Testing Furnace	L. H. Marshall Products 3000°F Tubular Furnace S/N 520383R	
Vickers Microhardness Tester	Riehle Testing Machine S/N R9365	USN 703040

REFERENCES

(1) J. F. Barker, "A Superalloy For Medium Temperatures", Metal Progress, Vol. 81, No. 5, May, 1961

(2) M. Kaufman and A. E. Palfy, "The Phase Structure of Inconel 718 and 702 Alloys", Trans. AIME, Vol. 221, December, 1961

(3) J. F. Barker, "Inconel 718 Phase Study Review", PM 61-183, General Electric Company, July 6, 1961

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TABLE 1

DPH VALUES FOR INCONEL 718

SPECIMEN CONDITION	AIR QUENCHED *						WATER QUENCHED *					
	1	2	3	4	5	AVE.	1	2	3	4	5	AVE.
MILL ANNEALED	184	191	191	188	187	188	---	---	---	---	---	---
30 HOURS/1400F.	358	356	362	358	358	358	---	---	---	---	---	---
30 HOURS/1400F. + 15 MIN./1500F.	321	321	313	313	321	318	315	319	313	325	315	317
+ 15 MIN./1600F.	212	214	216	216	218	215	217	215	215	216	217	216
+ 15 MIN./1700F.	190	187	187	188	187	188	187	187	188	188	187	187
+ 15 MIN./1750F.	187	186	185	188	182	186	185	188	188	187	188	187
+ 15 MIN./1800F.	184	185	185	187	185	185	184	183	183	183	185	184
+ 15 MIN./1900F.	181	180	179	179	179	179	179	180	181	180	178	180
+ 15 MIN./2000F.	158	158	158	156	155	157	157	155	155	156	158	156
+ 15 MIN./2100F.	160	155	158	155	153	156	160	157	158	156	156	157
+ 15 MIN./2150F.	151	151	150	150	151	151	152	152	153	150	150	151
MILL ANNEALED + AGED	441	438	435	441	435	438	---	---	---	---	---	---
30 HOURS/1400F. + AGED	396	404	404	401	399	401	---	---	---	---	---	---
30HOURS/1400F. + 15 MIN./1500F. + AGED	407	401	407	407	407	406	401	404	407	409	407	406
+ 15 MIN./1600F. +	423	423	423	423	426	424	432	426	426	426	423	427
+ 15 MIN./1700F. +	429	429	432	432	432	431	429	432	435	432	435	433
+ 15 MIN./1750F. +	441	435	435	435	441	437	438	432	441	435	441	437
+ 15 MIN./1800F. +	441	438	435	441	441	439	444	438	438	441	441	440
+ 15 MIN./1900F. +	447	438	438	441	444	442	441	444	444	441	435	441
+ 15 MIN./2000F. +	435	423	438	429	428	433	426	435	435	426	429	430
+ 15 MIN./2100F. +	426	435	435	435	429	432	441	435	426	426	426	431
+ 15 MIN./2150F. +	441	412	429	426	429	427	423	435	441	429	426	431

* TYPE OF COOLING FROM ANNEALING TEMPERATURE

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FIGURE 1A

HARDNESS AFTER ANNEALING

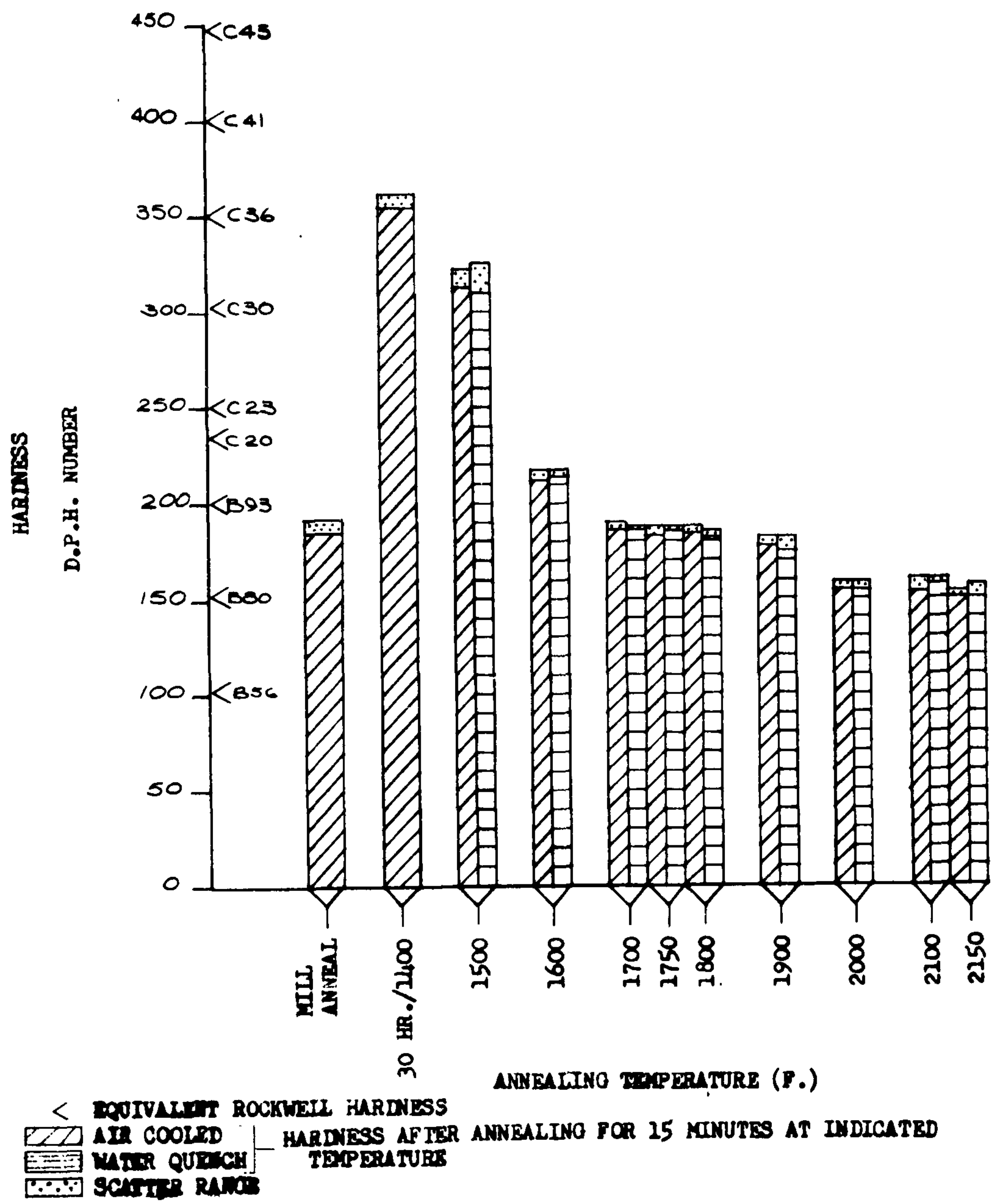

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FIGURE 1B
HARDNESS AFTER AGING ANNEALED MATERIAL

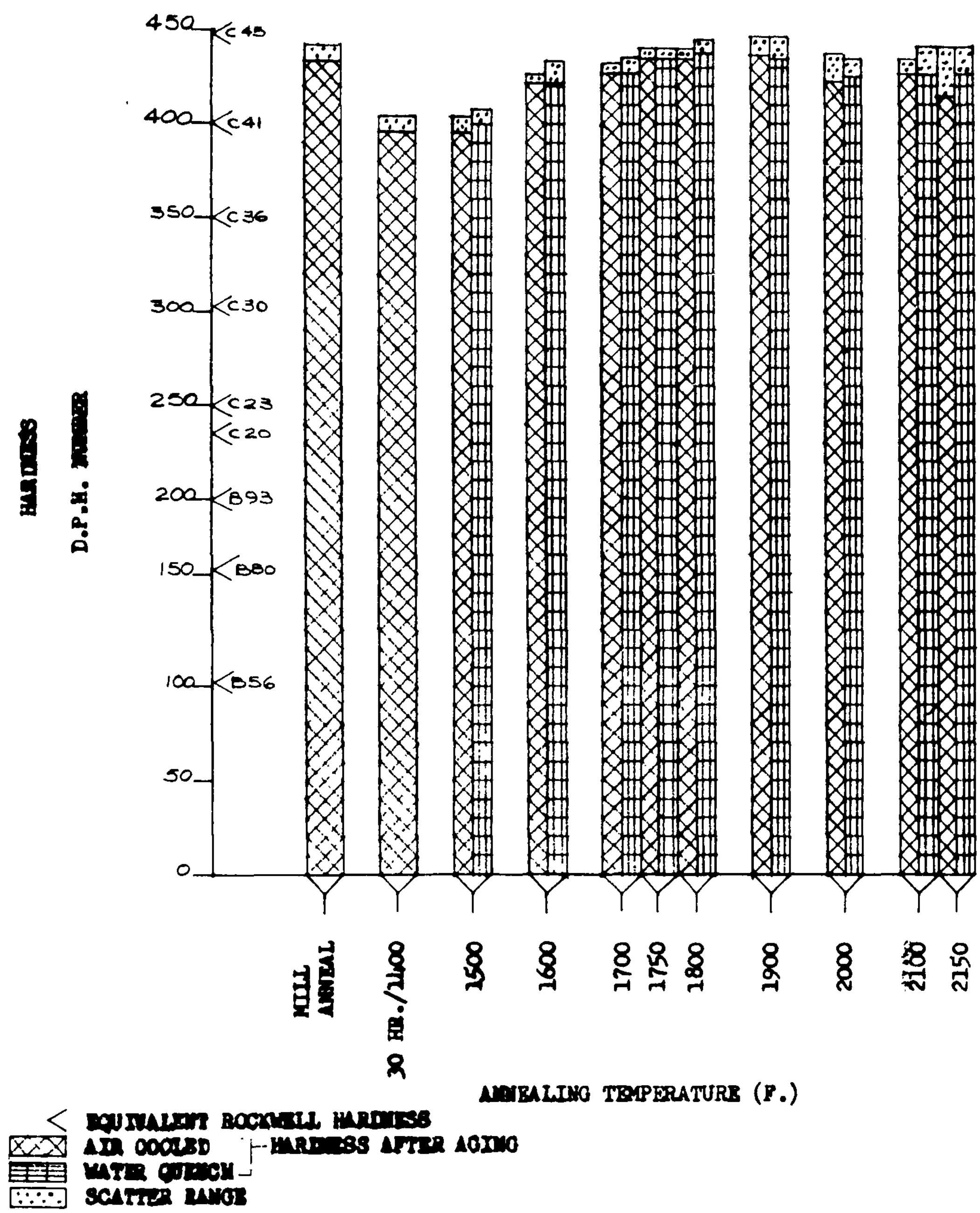

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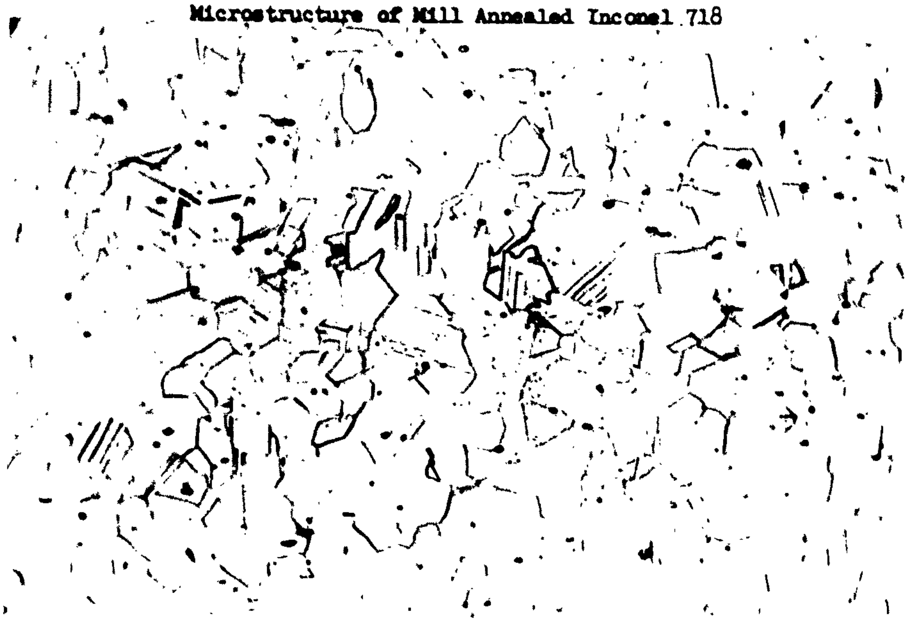
FIGURE 2

Microstructure of Mill Annealed Inconel 718



M10105 250X

M10041 2000X

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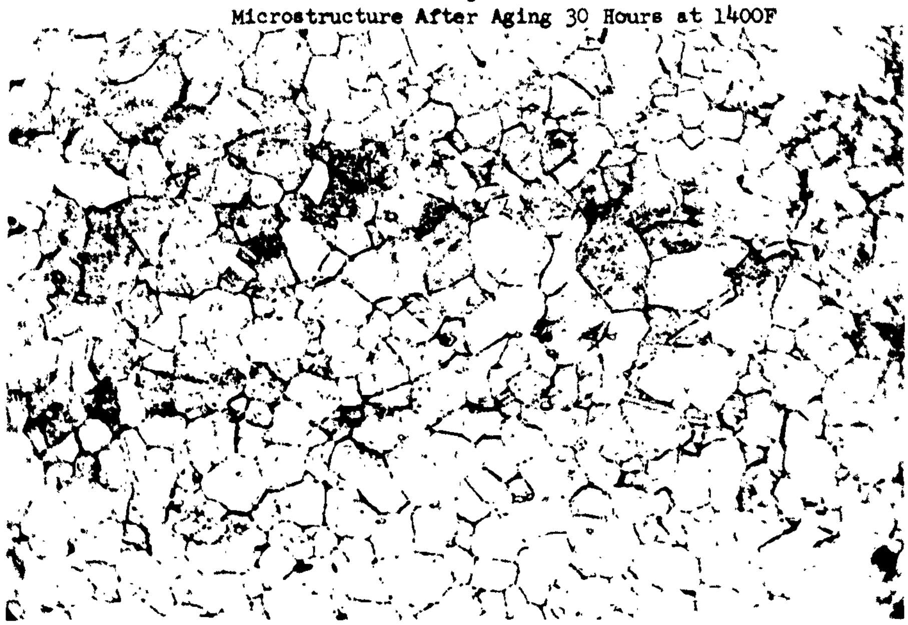
FIGURE 3
Microstructure After Aging 30 Hours at 1400F



M10090 250X

M10009 2000X

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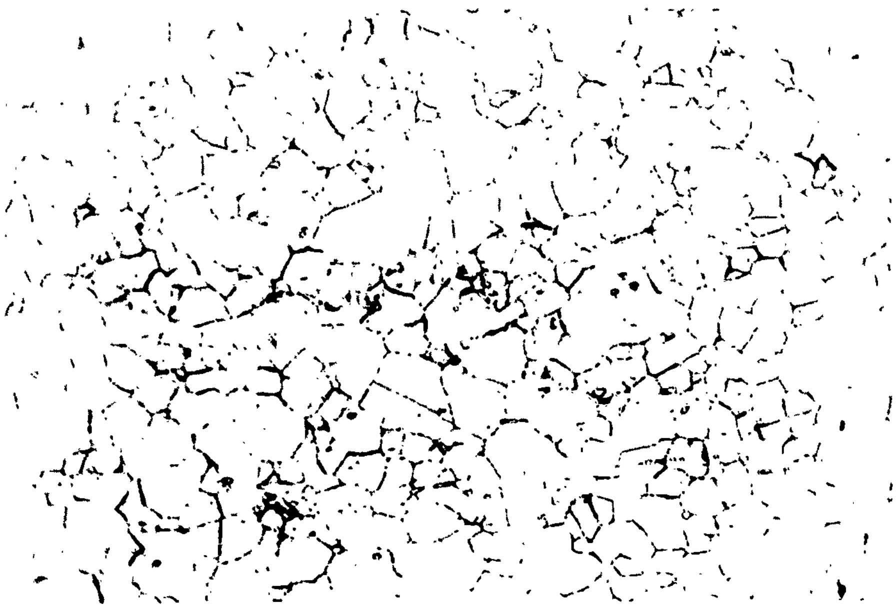
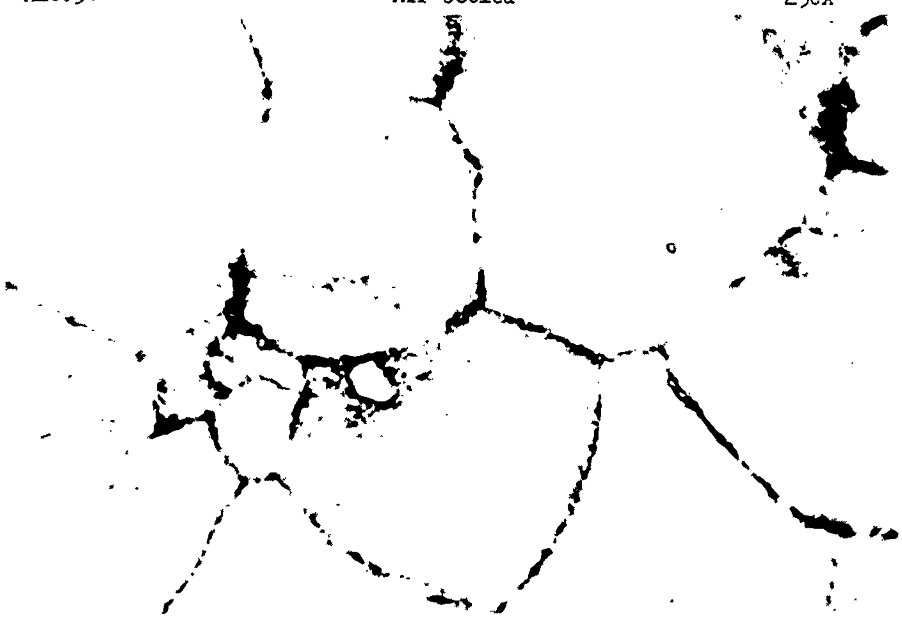
FIGURE 4

Microstructure After Annealing 15 Minutes at 1500F



M10094 Air Cooled 250X



M10026 Air Cooled 2000X

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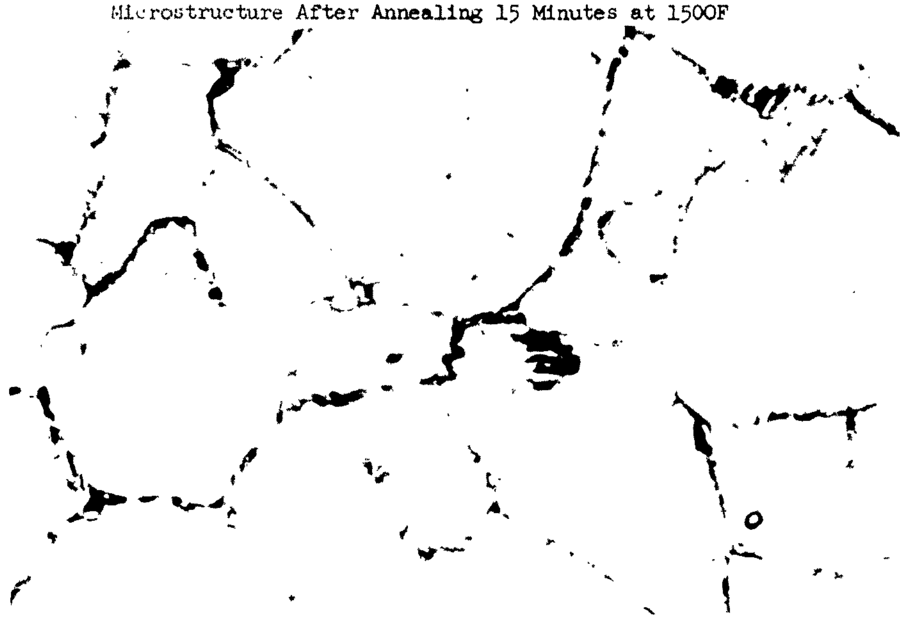
FIGURE 5

Microstructure After Annealing 15 Minutes at 1500F



M10024 Water Quenched 2000X

M10065 **Aged After Annealing** 2000X

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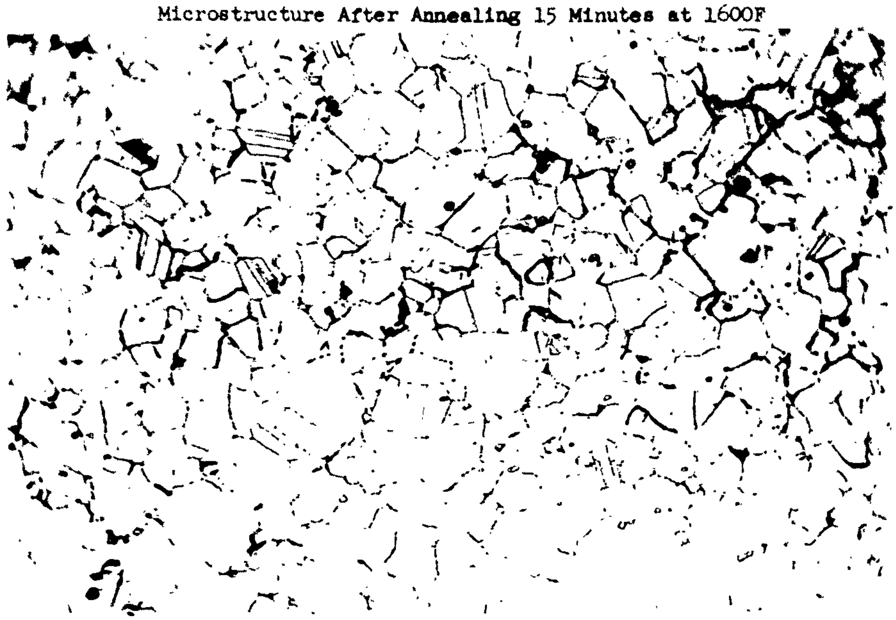
FIGURE 6
Microstructure After Annealing 15 Minutes at 1600F



M10088 Air Cooled 250X

M10011 Air Cooled 2000X

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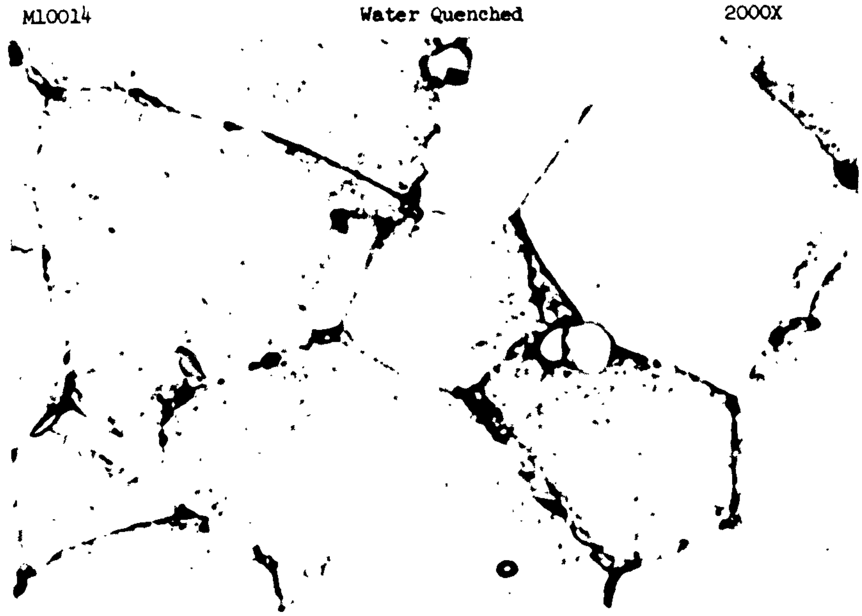
FIGURE 7

Microstructure After Annealing 15 Minutes at 1600F

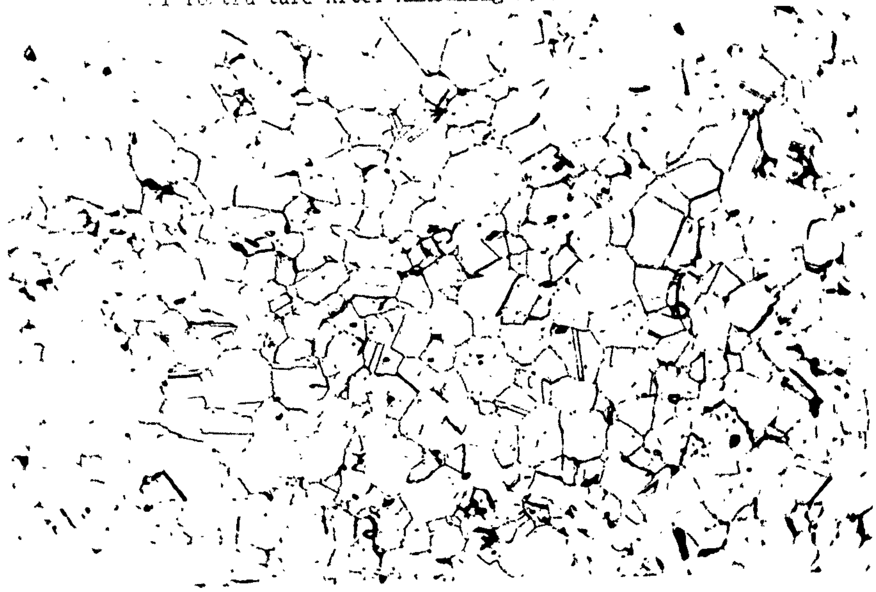
M10014 Water Quenched 2000X



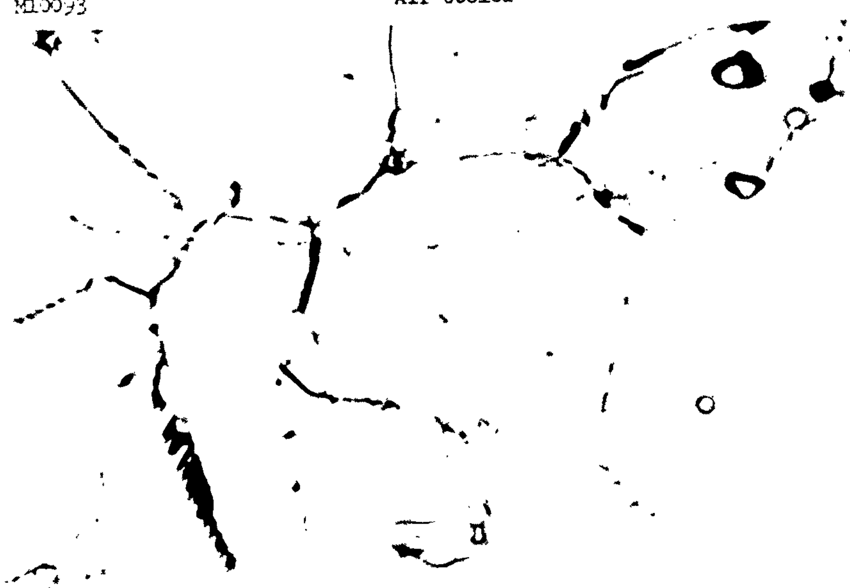
M10067 Aged After Annealing 2000X

FIGURE 6

Microstructure After Annealing 15 Minutes at 1700F



M10093 Air Cooled 250X



M10015 Air Cooled 2000X

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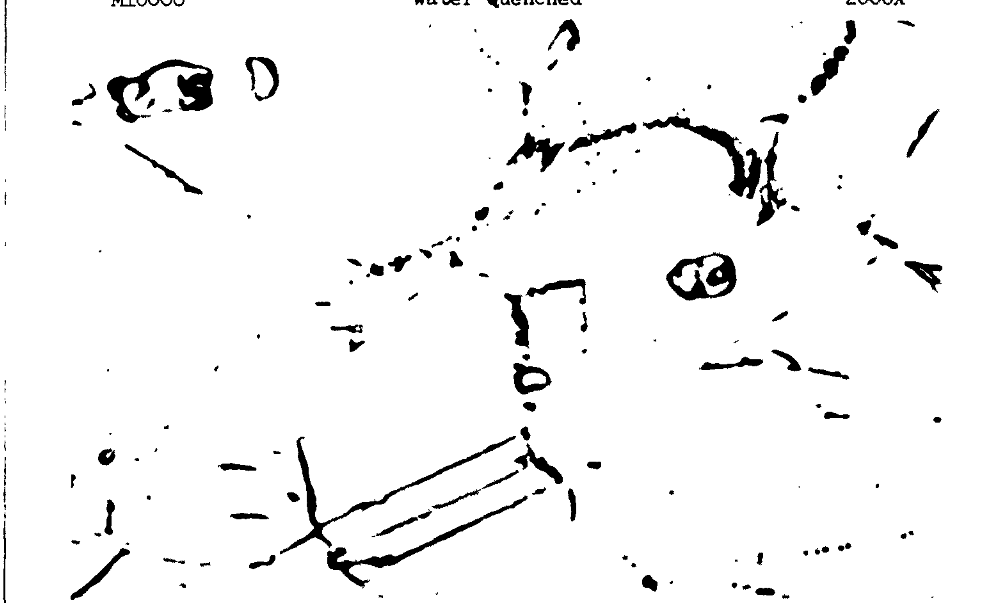
FIGURE 9

Microstructure After Annealing 1[illegible] Minutes at 17[illegible]F

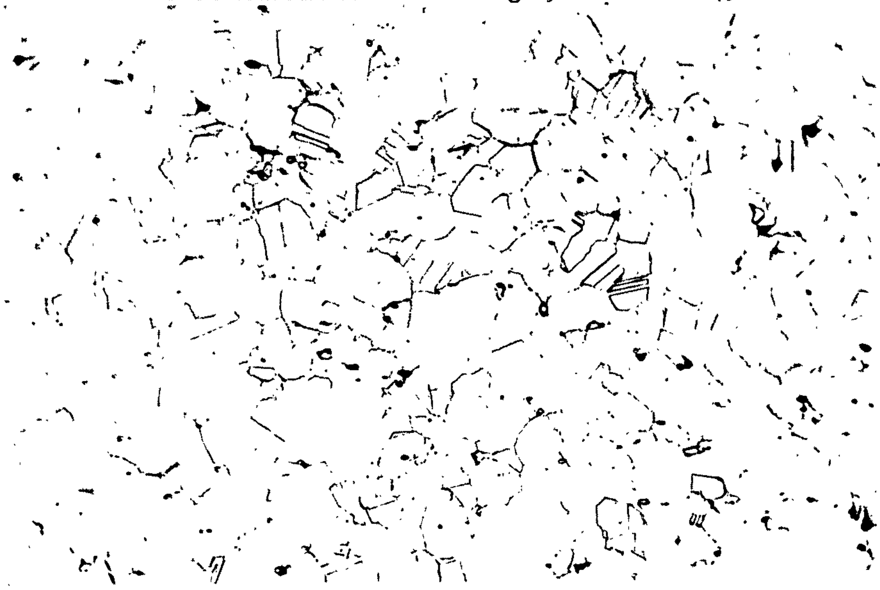
M10008 Water Quenched 2000X



M10069 **Aged After Annealing** 2000X

FIGURE 10

Microstructure After Annealing 15 Minutes at 1750F



M10086 Air Cooled 250X

M10021 Air Cooled 2000X

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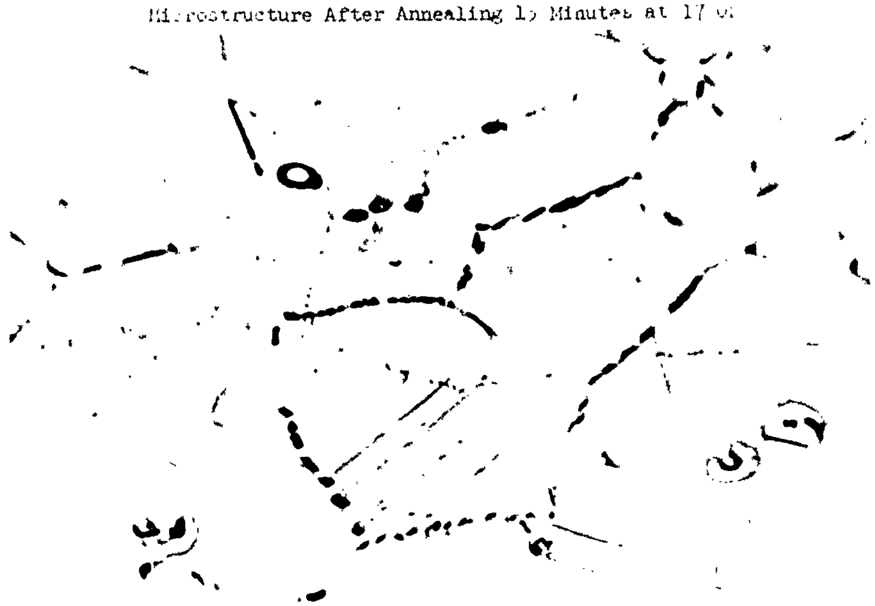
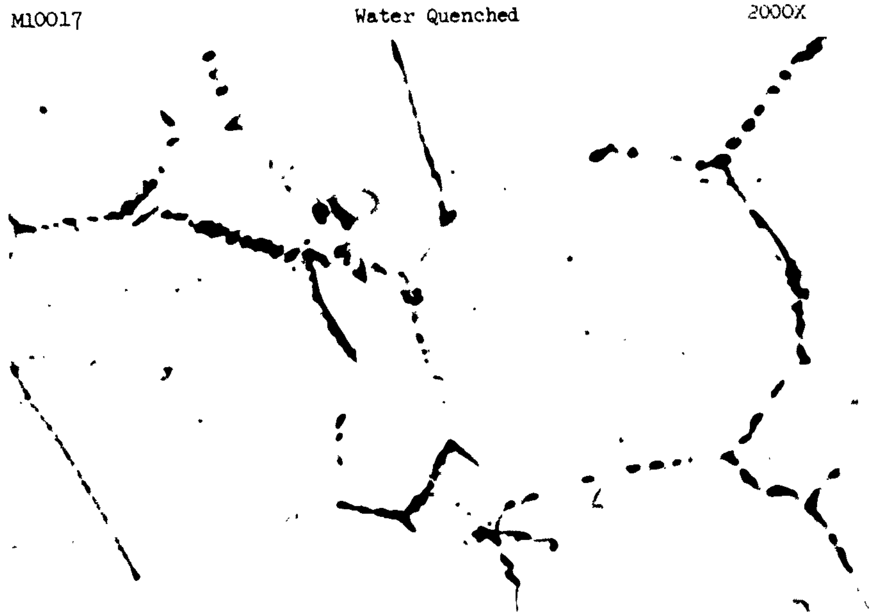
FIGURE 11
Microstructure After Annealing 15 Minutes at 17

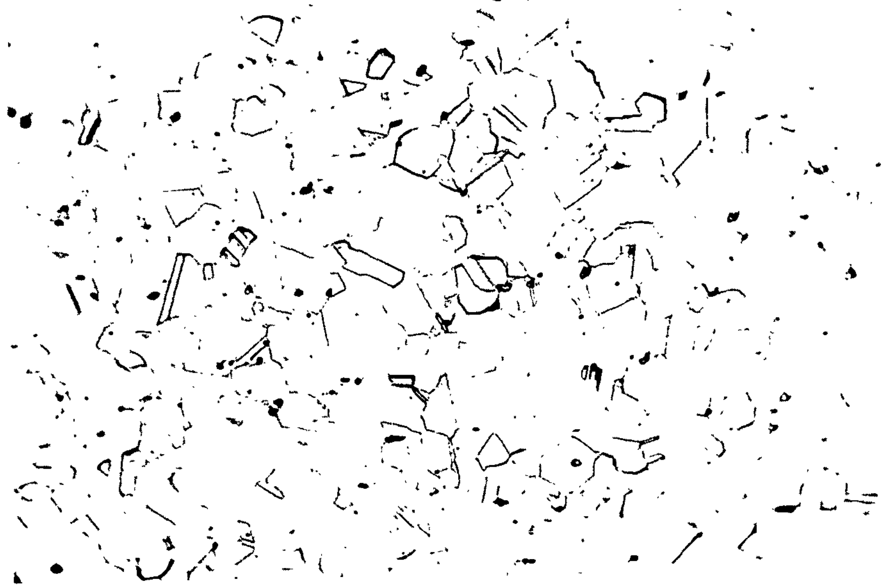


M10017 Water Quenched 2000X

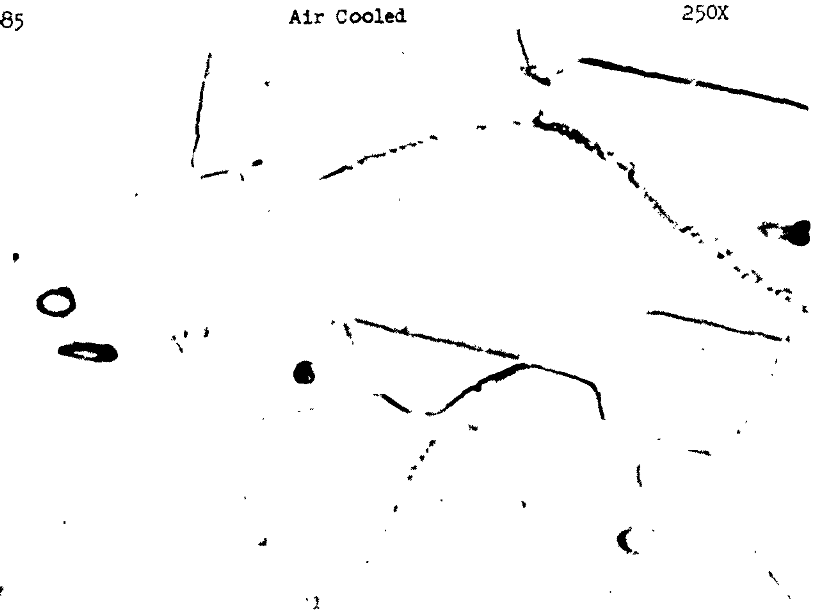


M10075 Aged After Annealing 2000X

FIGURE 12
Microstructure After Annealing 15 Minutes at 1800F



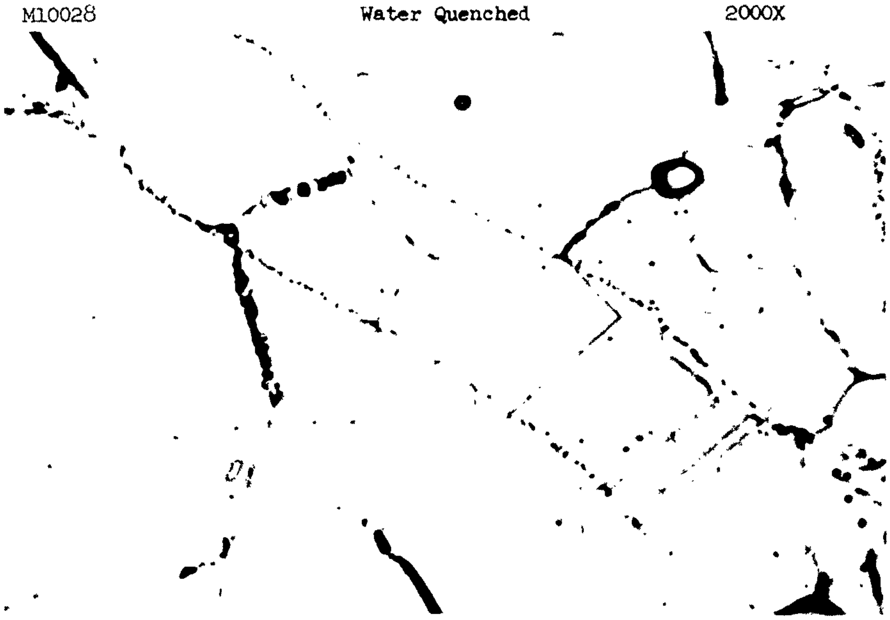
M10085 Air Cooled 250X



M10022 Air Cooled 2000X

FIGURE 13
Microstructure After Annealing 15 Minutes at 1800F

M10028 Water Quenched 2000X



M10081 **Aged After Annealing** 2000X

FIGURE 14

Microstructure After Annealing 15 Minutes at 1,00F

M10091 Air Cooled 250X

M10019 Air Cooled 2000X

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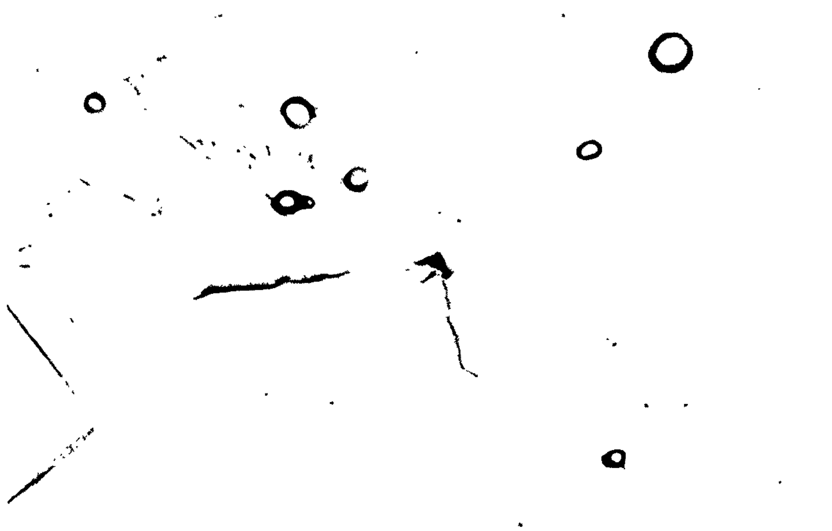
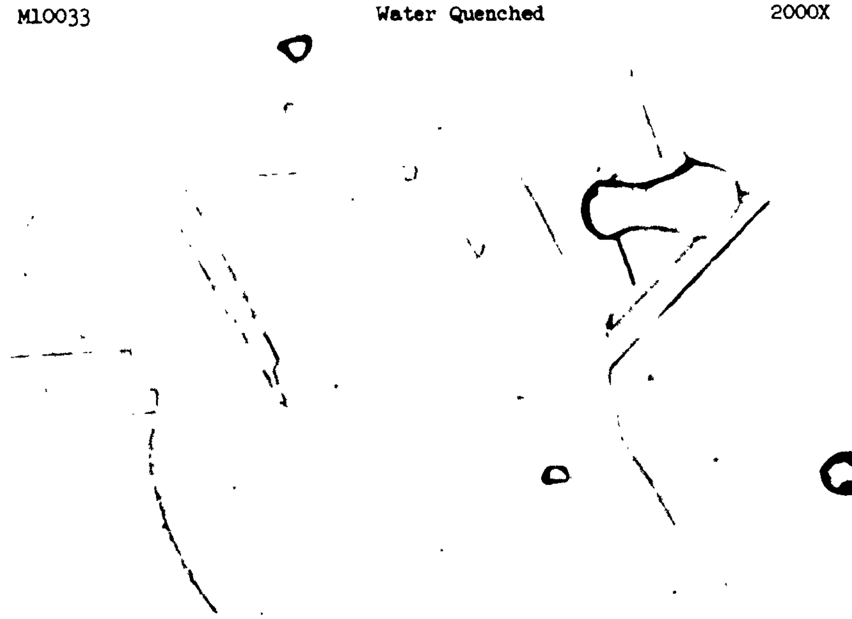
FIGURE 15
Microstructure After Annealing 15 Minutes at 1900F

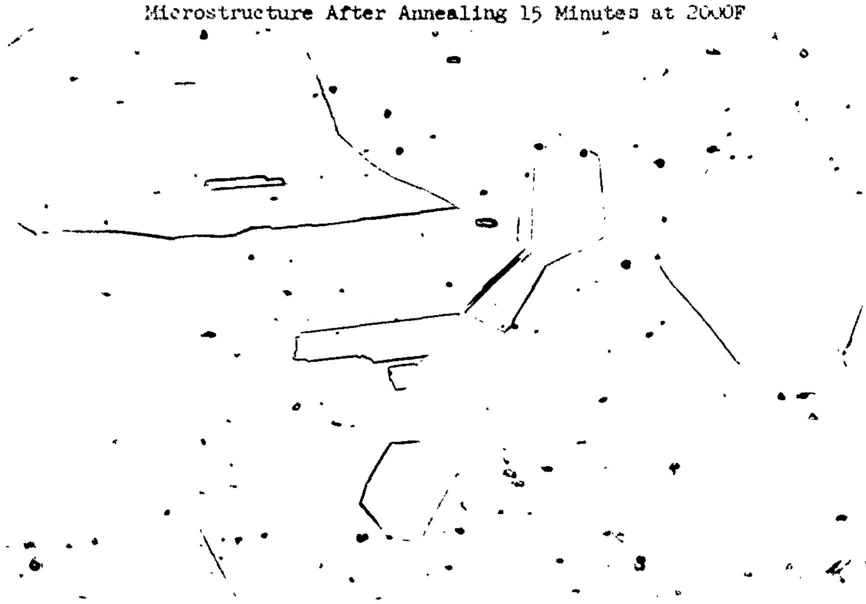


M10033 Water Quenched 2000X

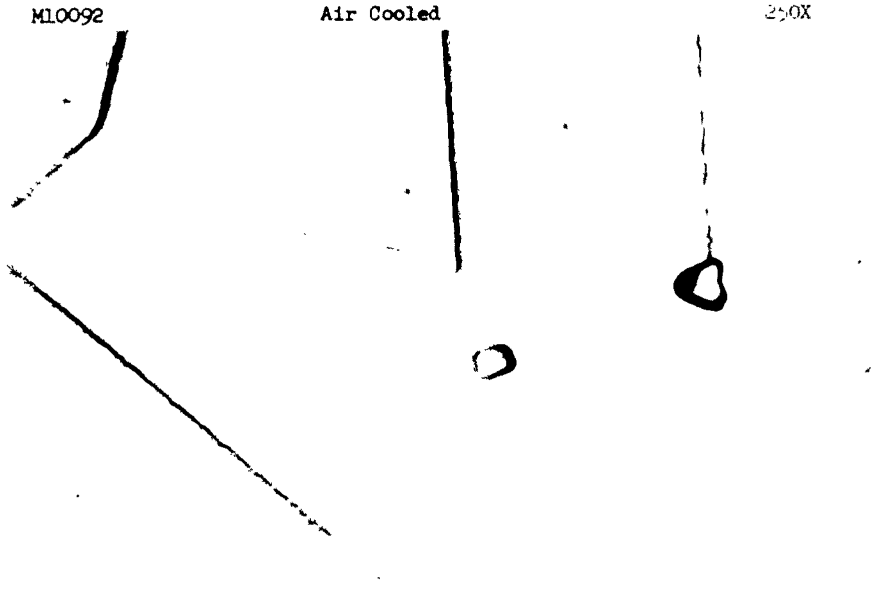


M10083 Aged After Annealing 2000X

FIGURE 16
Microstructure After Annealing 15 Minutes at 2000F



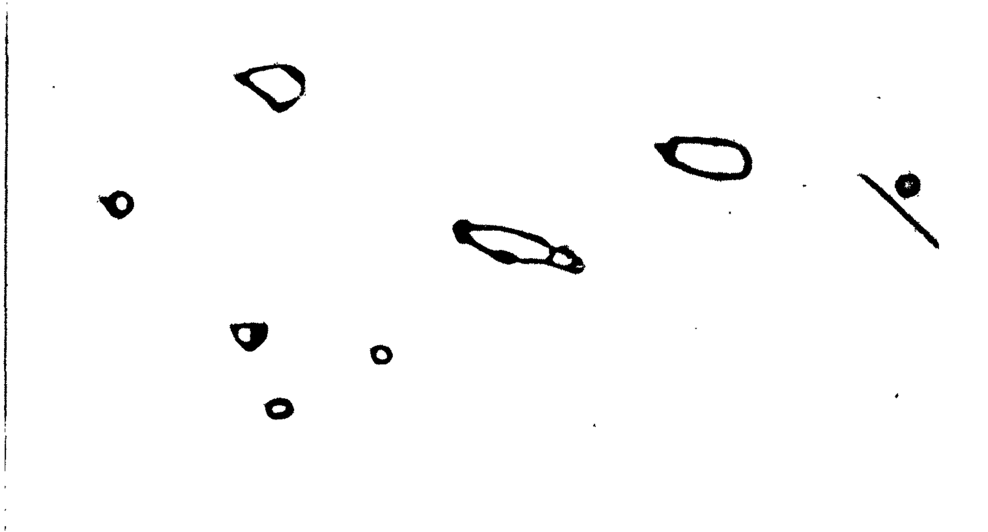
M10092 Air Cooled 250X



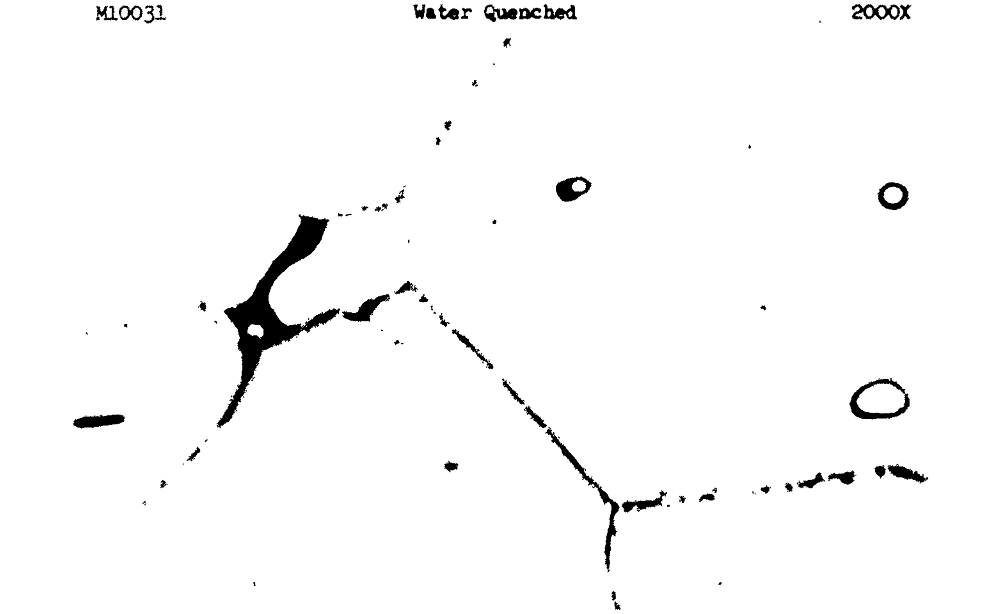
M10042 Air Cooled 2000X

FIGURE 17

Microstructure After Annealing 15 Minutes at 2000F



M10031 Water Quenched 2000X



M10082 Aged After Annealing 2000X

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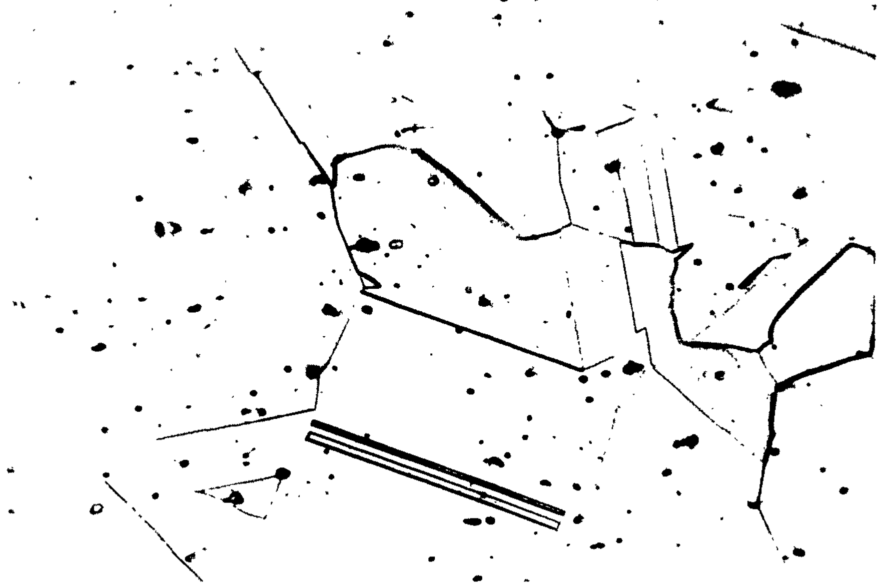
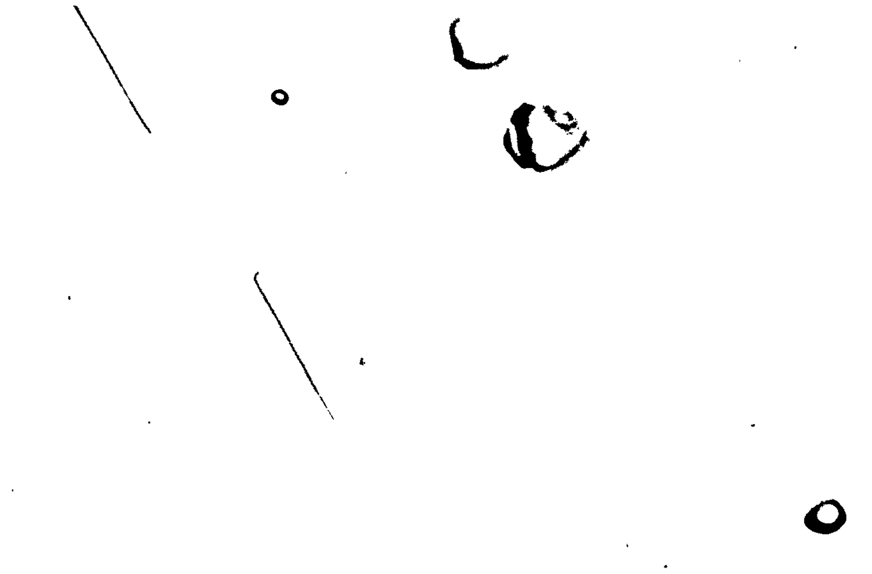
FIGURE 18
Microstructure After Annealing 15 Minutes at 2100F



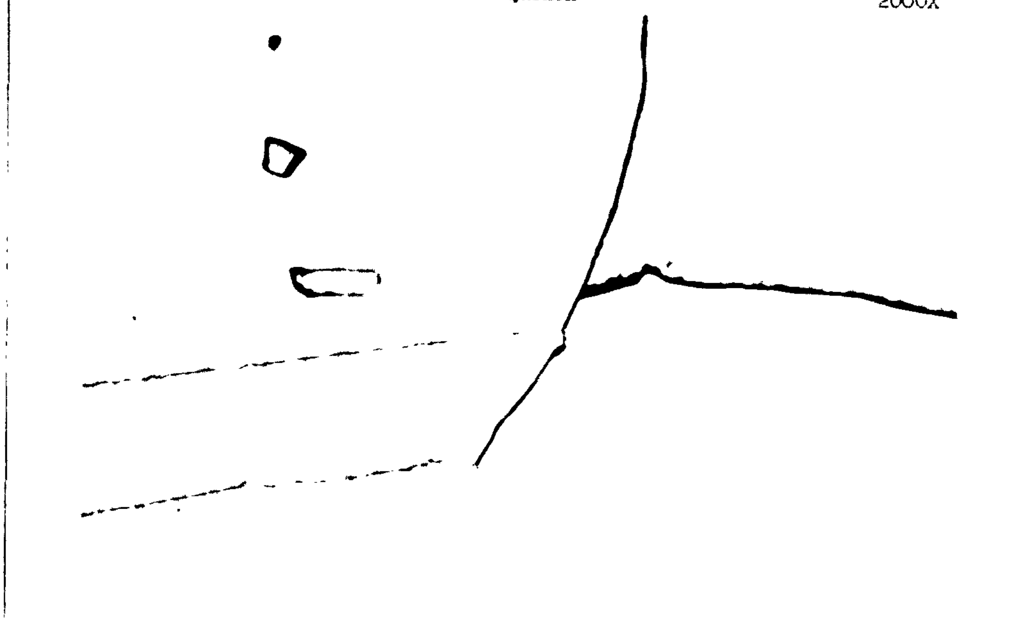
M10104 Air Cooled 250X



M10036 Air Cooled 2000X

FIGURE 19
Microstructure After Annealing 15 Minutes at 2100F

M10044 Water Quench 2000X

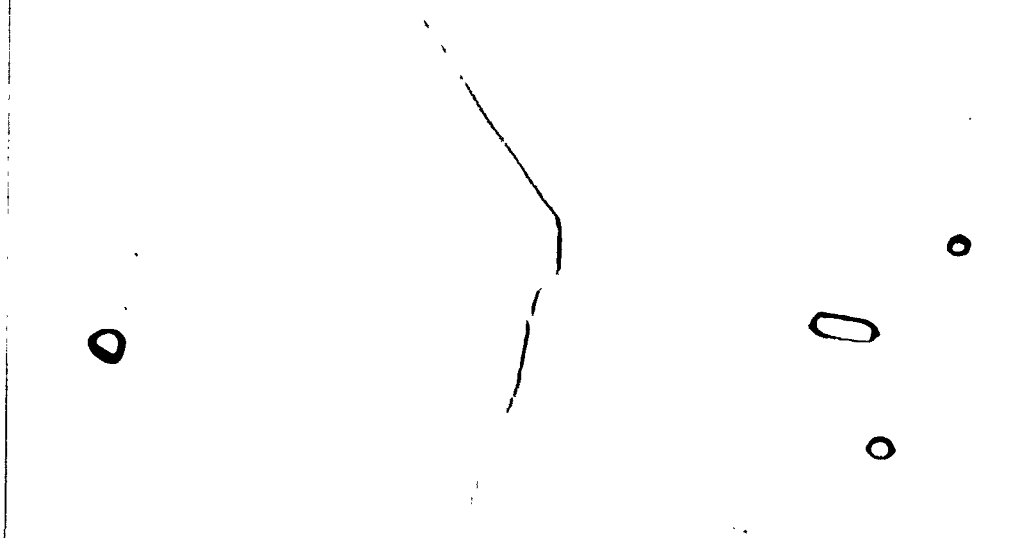


M10078 **Aged After Annealing** 2000X

FINAL REPORT

FIGURE 20
Microstructure After Annealing 15 Minutes at 2150F

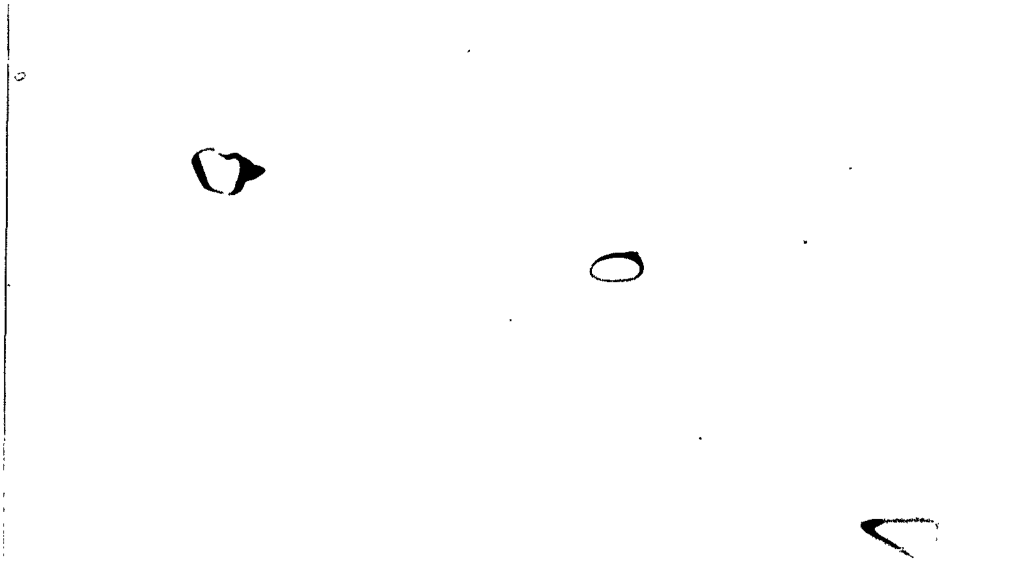
M10095 Air Cooled 250X



M10038 Air Cooled 2000X

FIGURE 21

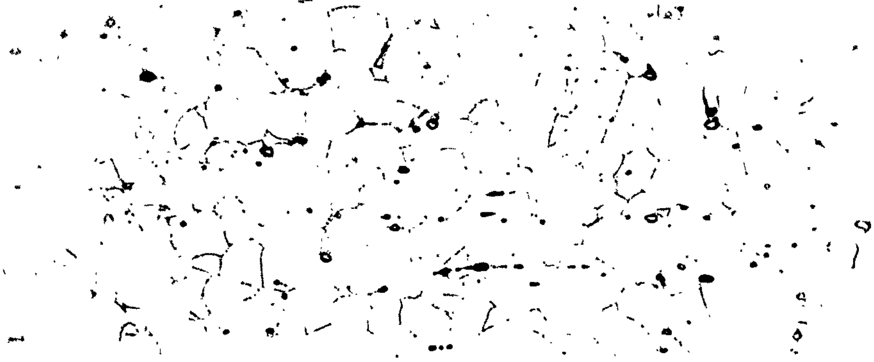
Microstructure After Annealing 15 Minutes at 2150F



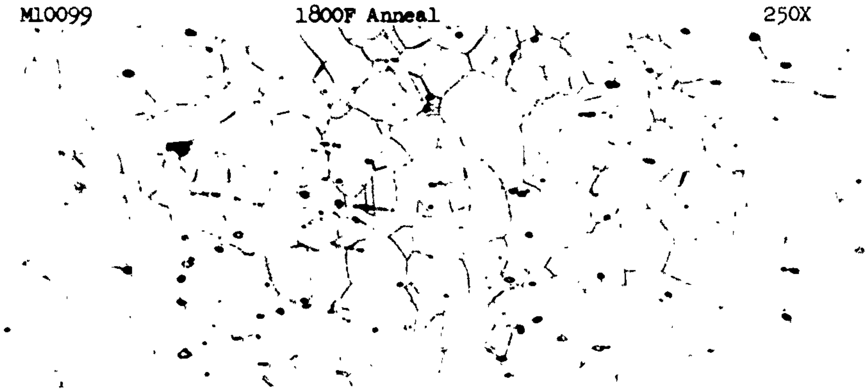
M10030 Water Quenched 2000X

M10077 **Aged After Annealing** 2000X

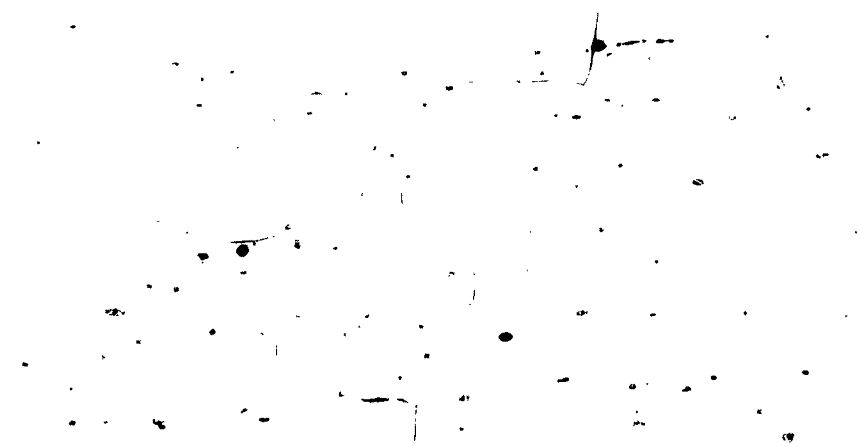
FIGURE 22
Microstructure of Specimens Aged After Annealing



M10099 1800F Anneal 250X



M10103 1900F Anneal 250X



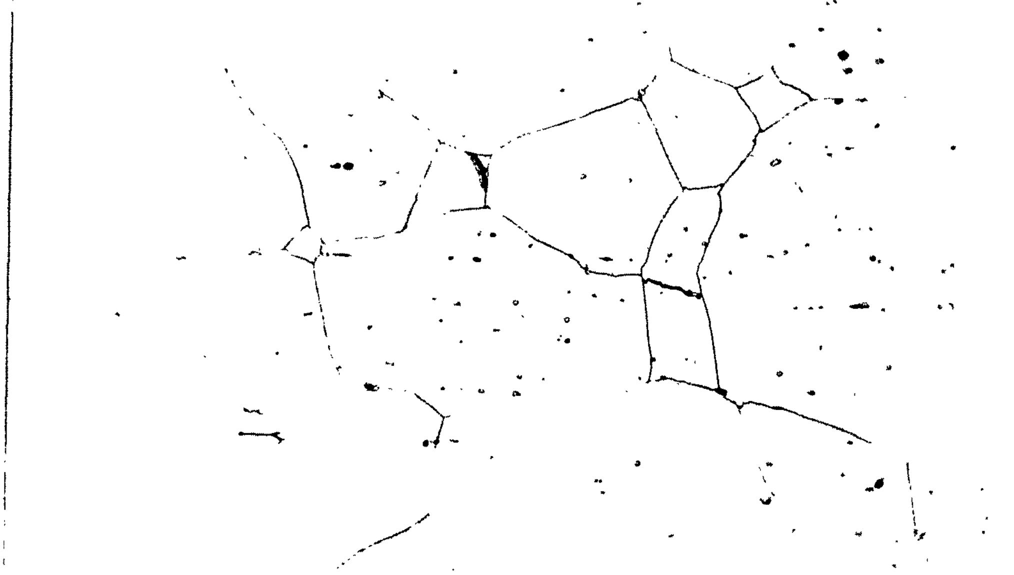
M10100 2000F Anneal 250X

D4Y-351324

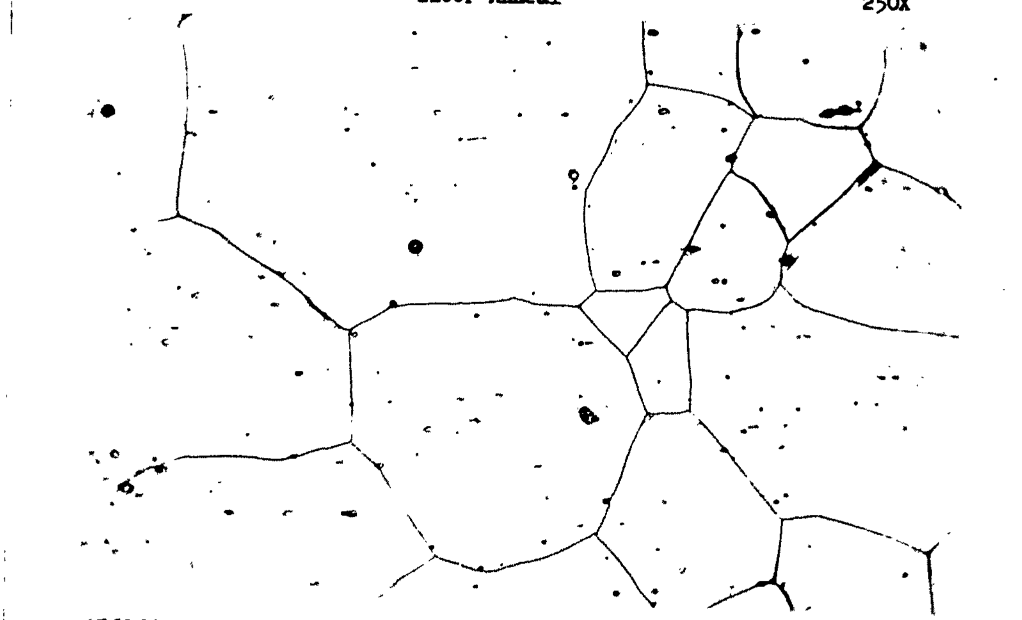
FINAL REPORT

FIGURE 23

Microstructure of Specimens Aged After Annealing



M10101 2100F Anneal 250X



M10102 2150F Anneal 250X

MAC 1006 (REV. 26 JAN. 59)
PAGE 1 OF 3

TEST REQUEST

TITLE EFFECT OF VARIOUS ANNEALING CYCLES ON INCONEL 718 MICROSTRUCTURE

LABORATORY OR DEPT. RESPONSIBLE FOR TEST	MODEL
Dept 253	Misc.
TEST PARTS ON IBM ☐ ; ON TPL NO.____ PRODUCTION PARTS FOR TEST NOT REQUIRED ☒	APL/EPI None

OK for IDEP WORK REQUESTED (Ni-4)(I-e)(IV-e)

OBJECTIVE (GIVE PURPOSE OF TEST, WORK AND DATA REQUIRED, INCLUDING SERVICE HISTORY AND BACKGROUND INFORMATION)

1.0 OBJECT

To investigate the effect of various annealing cycles on grain size and precipitate morphology in the nickel-chromium alloy Inconel 718.

2.0 HISTORY

Inconel 718 is being used and planned for many applications at MAC. The alloy normally requires annealing and aging heat treating cycles during fabrication and cycles used have been based on recommendations from the International Nickel Co. and internally generated mechanical property data.

3.0 JUSTIFICATION

Metallographic studies of Inconel 718, subjected to various annealing cycles, will provide background information needed to deviate, if necessary, from normal annealing cycles when difficulties are encountered during fabrication.

4.0 MATERIALS

38 pieces - 0.040" x 0.5" x 1.0" nickel-chromium alloy, Inconel 718, cold rolled, annealed temper, pickled finish (Material available from previous procurement)

Rev A Adds Actions
1-16-63

REFERENCES OR ENCLOSURES

Applicable to IDEP unless final report is classified. Report Summary Sheet, MAC 1008TRS required. Complete Report Summary Sheet and forward along with vellum copy of complete report to MAC IDEP Coordinator Dept. 261, Bldg. 33.

5.0 IDENTIFICATION

Identify, by steel stamping, all pieces from 4.0 as follows:

5.1 A1, A2 (2 specimens, to be examined as overaged)

5.2 B1, B2, B3, B4 (4 specimens, 1500F anneal)

5.3 C1, C2, C3, C4 (4 specimens, 1600F anneal)

5.4 D1, D2, D3, D4 (4 specimens, 1700F anneal)

5.5 E1, E2, E3, E4 (4 specimens, 1750F anneal)

5.6 H1, H2, H3, H4 (4 specimens, 1800F anneal)

5.7 K1, K2, K3, K4 (4 specimens, 1900F anneal)

5.8 L1, L2, L3, L4 (4 specimens, 2000F anneal)

5.9 M1, M2, M3, M4 (4 specimens, 2100F anneal)

5.10 P1, P2, P3, P4 (4 specimens, 2150F anneal)

6.0 HEAT TREATMENT (All temperatures ± 25F)

6.1 Overage all specimens from 5.0 by furnace heating at 1400F for 30 hours, air cool.

6.2 Anneal the B specimens from 5.2 at 1500F for 15 minutes. Air cool 1 and 2; water quench 3 and 4.

6.3 Repeat 6.2 with C specimens using 1600F anneal.

6.4 Repeat 6.2 with D specimens using 1700F anneal.

6.5 Repeat 6.2 with E specimens using 1750F anneal.

6.6 Repeat 6.2 with H specimens using 1800F anneal.

6.7 Repeat 6.2 with K specimens using 1900F anneal.

6.8 Repeat 6.2 with L specimens using 2000F anneal.

6.9 Repeat 6.2 with M specimens using 2100F anneal.

6.10 Repeat 6.2 with P specimens using 2150F anneal.

TEST REQUEST NO. 513-336

7.0 METALLOGRAPHIC EXAMINATION

7.1 Send all specimens identified with 1's and 3's to L. Flanigan, Dept. 272, Bldg. 33.

7.2 Section and prepare for metallographic examination, by electrolytic etching only, all specimens identified with 2's and 4's.

7.3 Prepare photomicrographs (highest magnification available) of all mounts from 7.2 showing the microstructure resulting from each thermal treatment.

7.4 Determine grain size of all specimens from 7.2 in accordance with ASTM standards.

7.5 Compare the relative quantities of grain boundary precipitate observed in all specimens from 7.2 using the over-aged sample (A2) as a reference. (Use optical metallographic technique)

7.6 Compare the relative quantities of intragranular precipitate of all specimens from 7.2 using the overaged sample (A2) as a reference.

7.7 Resolve and compare the precipitated phases as completely as possible using optical metallographic techniques.

8.0 DATA REQUIRED

8.1 Actual heat treat cycles

8.2 Photomicrographs of all specimens examined

8.3 Grain size of all specimens per ASTM standards

8.4 Relative quantities of precipitates as compared to the "over-aged only" specimen (A2), percent remaining

8.5 Comparison of precipitated phases